

COMPONENT PLACEMENT

Background

The invention relates to component placement.

In general, one goal of electronic equipment manufacturers is to run production lines as quickly and efficiently as possible. To this end, manufacturers extensively use electronic automation to design and produce electronic assemblies. For example, printed circuit boards typically are assembled by "pick-and-place" machines that automatically select an electronic component for placement on a board, properly align the component and the board, and place the component on the board. These machines manufacture printed circuit boards much faster than human workers can.

Referring to Figure 1A, one type of pick-and-place system often used in industry is a rotating turret-style system 20, such as the CP-series machines produced and sold by Fuji Manufacturing Company. In the turret-style system 20, a rotating turret 22 uses suction arms 24 to pick components 26 from a component table 28 and to place them on a circuit board 30 mounted onto an x,y-table 32. The turret 22 has several arms 24 so that it may pick one component from the component table 28 while it places another component onto the circuit board 30.

Referring also to Figure 1B, the component table 28 holds reels 34 of tape 36 onto which the components 26 are mounted. When a turret arm 24 picks a component, the component table 28 rotates the reel 34 to expose the next component. The component table 28 moves in the x-direction so that after the system 20 has placed all of the components on one reel, the table 28 may move the next reel into position.

The x,y-table 32 properly positions the printed circuit board to receive components by moving the board in the x-, y-, and z-directions. In most situations, a complex optimization algorithm is used to attempt to minimize the x-, y-, and z-direction movement of the x,y-table 32 and the x-direction movement of the component table 28 while maximizing the rotational speed of the turret 22. Conventional optimization algorithms treat each component type as an individual entity, although most turret-style machines can pick components from any one of three adjacent component reels 34 without any significant reduction in placement speed. The turret 22, component table 28, and x,y-table 32 are controlled by one or more controllers 33 under the direction of a placement program generated by the optimization algorithm.

Referring to Figure 2, a "shortest path optimization" algorithm is commonly used for component placement. The typical shortest path algorithm determines, for each type of component P, Q on a printed circuit board 38, the order in which the components should be placed to minimize the length of the placement path 40. The algorithm generally begins with the component type P that occurs most frequently on the board 38, then proceeds to the next most common component type Q. The shortest path calculation for the less common component type Q begins at the end 42 of the placement path 40 for the more common type P.

Summary

In one aspect, the invention features automatically controlling the placement of components on a circuit board. A group containing two or more types of components to be placed on the circuit board is created, and a placement path by which any component within the group may be placed on the

circuit board at any point along the placement path is developed.

Embodiments of the invention may include one or more of the following features. The group of components may be created by identifying two types of components that are to be closely situated at many locations on the circuit board and defining the group to contain components of the two types. The group also may be defined to include a third type of components that is to be closely situated to at least one of the other two types of components at several locations on the circuit board. Several areas may be defined on the circuit board, and the group may be defined to include types of components that appear together in a large number of areas. The group may include two types of components that appear together in more of the areas than any other two types of components. The areas may overlap each other, and each of the areas may be a block defined by a grid.

The placement path may be developed by calculating substantially the shortest path required to place all components in the group on the circuit board. An additional group may be created for every three types of components to be placed on the circuit board, and a placement path may be developed for each of the additional groups. The placement path for each additional group may begin where the placement path for a previous group ends. The components in each group may be placed on the circuit board according to the corresponding placement path.

In another aspect, the invention features a method of defining a sequence for placing components of multiple types in predefined locations on a circuit board. The components are organized into groups each containing at least two of the types of components. Components of a given

one of the groups are placed on the circuit board, and thereafter components of another one of the groups are placed on the circuit board.

Embodiments of the invention may include one or more
5 of the following features. All of the components of one group may be placed before any components of another group. The components of one group may be placed in an order such that any position in the order may be occupied by a component of any of the types contained in the group. The
10 order in which the components of a group are placed may be determined by the shortest path required to place the components in the group. The types of components contained in each of the groups may be determined by the frequency with which components of different types appear in close
15 proximity to each other. One group may contain the two types of components that most frequently appear in close proximity to each other. The group also may contain a third type of components. The components may be grouped based upon how frequently components of different types appear
20 together within predefined placement areas. Each of the groups may contain three types of components.

In another aspect, the invention features a method of placing components of multiple types in accordance with a sequence defining an order in which the components are
25 placed in predefined locations on a circuit board. In a subsequence of the sequence, multiple components which belong only to a first group of at least two of the types of components are placed. Likewise, components belonging to at least one additional group of at least two different types
30 of components are placed.

In another aspect, the invention features a system for placing components on a circuit board. The system includes a placement machine configured to place the

components according to groups containing at least two types of components and a controller that governs the operation of the placement machine such that components of a given one of the groups are placed on the circuit board and thereafter
5 components of another one of the groups are placed.

Embodiments of the invention may include one or more of the following features. The placement machine may be a turret-style machine. The system also may include a component table that stores the components such that the
10 components within each group occupy adjacent positions in the component table.

Advantages of the invention may include one or more of the following. Printed circuit board motion may be reduced during component placement, so the chances of
15 jarring loose previously placed components may decrease. The time required to place components on a circuit board may be reduced by more than five percent, which provides greater production efficiency.

Other features and advantages of the invention will
20 become apparent from the following description and from the claims.

Description

Figure 1A is a top view of a component placement machine.

25 Figure 1B is a perspective view of a component tape reel.

Figures 2 and 3 are top views of printed circuit boards.

Figure 4 is a block diagram of a computer system.

30 Figure 5 is a flow diagram of a component grouping program.

Figure 6 is a table containing a list and a count of components on a printed circuit board.

Figure 7 is a top view of a printed circuit board divided into grid blocks.

Figure 8 is a table containing a list and count of components for each grid block in Figure 7.

5 Figure 9 is a chart containing a list of component pairs for each grid block of Figure 7.

Figure 10 is a table containing a grid count for the component pairs of Figure 9.

10 Figure 11 is a table containing a list of component groups.

Figure 12 is a top view of component reels grouped in a component table.

Figure 13 is a flow chart for a shortest path optimization routine.

15 Figure 14A is a sequence listing for component placement.

Figure 14B is a circuit board with components placed according to the sequence of Figure 14A.

20 Figure 15 is a partial top view of a printed circuit board divided into overlapping grid blocks.

Referring to Figure 3, a printed circuit board 76 may include many different types of components A, B, C, D, E, F, and G. The circuit board 76 may include electronic components, such as resistors, capacitors, inductors, processors, memory devices, and logic circuits, and it may include mechanical components, such as switches and connectors. Some component types (e.g., type A) appear frequently on the board 76, while others (e.g., type C) do not. Also, some areas of the board (e.g., area 78) are heavily populated with components, while other areas (e.g., area 80) are not.

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Referring also to Figure 4, a computer system 50 may be used to design a "layout" for the printed circuit board

(i.e., a roadmap for placement of the components on the circuit board) and to organize the components into groups for "simultaneous" placement on the circuit board. To design the board layout, a computer processor 52 uses a
5 board layout program 54 stored in memory 55. The layout program 54 typically is an interactive program that allows a user to provide information to the processor 52 through input devices, such as a keyboard 56 or a mouse 58. The processor may output information, such as a video image 60
10 or prints 62 of the layout, through output devices, such as a video display 64 or an image printer 66. The layout program 54 also generates a board layout file 68, which may be stored on any fixed or portable storage medium (neither shown). The board layout file 68 identifies each of the
15 components included on the circuit board and the corresponding component type. The layout file 68 also identifies each component's exact location, as determined by the x,y-coordinate of its centroid with respect to a reference point (origin) on the circuit board, such as the
20 board's lower left corner 82 (Figure 3).

A component grouping program 70, also stored in memory 55, uses the information contained in the board layout file 68 to identify the types of components to be included on the circuit board and to determine the quantity
25 and locations of each component type. Based on these determinations, the grouping program 70 organizes the components into groups for "simultaneous" placement and generates a set of grouping instructions 72. The grouping instructions treat all components in a group as a single
30 component type.

A shortest path optimization program 74 in memory 55 uses the grouping instructions 72 to calculate the shortest placement path for each component group. Because the

grouping program identifies all components in a group as a single component type, the optimization program calculates the shortest path for the group as a whole rather than for the individual component types that make up the group. The
 5 results of the shortest path optimization are stored in a placement instructions file 75, which is used, e.g., by the controller 33 of Figure 1A to govern the placement of components on a circuit board.

Referring to Figure 5, the component grouping
 10 program begins by retrieving 84 the board layout file and parsing it to generate 86 a list of the types of components and a count of each type. Figure 6 is a table containing a list and a count of component types for the circuit board of Figure 3. Next, the program divides 88 the circuit board
 15 into a grid (Figure 7) and generates 90 a list and a count of component types in each block of the grid (Figure 8). The program then generates 92 a list of component pairs in each grid block (Figure 9), which it uses to count 94 the number of grid blocks containing each of the component pairs
 20 (Figure 10). The program then organizes 96 the component types into groups for "simultaneous" placement (Figure 10) and calculates 98 the shortest placement path for the components in each group, as well as for each ungrouped (single) component type. A sample code for the grouping
 25 program is contained in the attached Appendix.

Referring to Figure 7, the grouping program uses information from the board layout file to determine the size of the circuit board 76 and to divide it into a grid. Grid lines X1, X2, X3, X4 and Y1, Y2, Y3 are created along the x-
 30 and y- axes, respectively, to divide the board 76 into equally-sized rectangular areas 100 ("grid blocks"). The lines are equally spaced, preferably by a distance of approximately twenty millimeters. Thus, a 10cm x 8cm board

76 is divided into approximately twenty grid blocks 100 (5 x 4).

Referring also to Figure 8, the grouping program determines which types of components A-G fall into the various grid blocks 100 and counts how many components of each type A-G appear in each block. To do so, the program performs a "less-than-or-equal-to" comparison of the x,y-coordinate for each component's centroid (not shown) to the x-coordinate or y-coordinate of the grid lines X1, X2, X3, X4, and Y1, Y2, Y3, respectively. Thus, a component whose centroid has an x-coordinate less than or equal to the x-value of line X1 and a y-coordinate less than or equal to the y-value of line Y1 falls into grid block 1-1. Likewise, a component whose centroid has a an x-value greater than that of X4 and a y-value greater than that of Y3 falls into grid block 5-4. Because the program performs a "less-than-or-equal-to function," a component whose centroid lies on a grid line falls into the leftmost or lower grid block.

As an example, consider grid block 2-3, which entirely contains one type B component, one type E component, and one type G component, but only partially contains a second type E component and components of types A, C, D, and F. Because the centroid 102 of the type C component clearly lies within grid block 2-3, the grouping program lists the type C component as a member of that block. The same is true for the type D component. The location of the type F component, which partially lies in four grid blocks (2-3, 3-3, 2-4, 3-4), is not as clear. But because the centroid 104 of the type F component lies on line X2 and below line Y3, it also falls within block 2-3. The centroids (not shown) of the type A component and the second type E component are outside grid block 2-3, so the program does not list these components as members of block

2-3. Therefore, grid block 2-3 contains one component of every type except type A.

Referring also to Figure 9, after the grouping program lists and counts the components in the various grid blocks 100, it determines and lists the component pairs appearing in each block. For example, grid block 1-1 contains one type A component and two type E components, so the program lists component pair A-E as the only pair in block 1-1. Because block 2-3 contains every component type except type A, the program lists for this block all component pairs that exclude type A.

Referring to Figure 10, the grouping program then lists each component pair 106 that appears on the board and a count 108 of grid blocks in which each pair appears. The component pair that appears most often (A-E, nine blocks) tops the list, while the component pair that occurs least often (A-C, C-D, C-E, C-F, 1 time each) is listed last.

Referring also to Figure 11, the grouping program uses the list of component pairs (Figure 10) to organize the components into groups 110 of three component types. The program creates the first component group 112 by selecting the two component types A, E that make up the pair which occurs most often (A-E). If two or more component pairs appear the same number of times but more than any other pairs, the program selects the pair that includes the highest total number of components on the board. For example, if pairs A-E and A-D had appeared in the same number of grid blocks (Figure 10), the program would select pair A-E because the board contains 52 components of type A and type E, which is more than the 39 type A and type D components (Figure 6).

The program then rounds out the first component group 112 by selecting the component that most frequently

occurs with one of the two previously selected component types A, E. Because component types B, D, and F occur equally frequently with one of the selected components A, E (Figure 10), the program must select the third component using one of four possible tie-breaking methods. First, the program may select the component type that occurs most often on the circuit board (Figure 6). Second, if the program must choose between two components that are paired with the same component from the first pair, the program may choose the component that occurs most frequently with the other component from the first pair. Thus, if the first pair chosen is pair A-E and pairs A-B and A-D are the remaining pairs that occur most often, then the program may choose the component type (B or D) that occurs most often with type E components. Third, if the program must choose between two components each paired with a different member of the first pair, the program may choose the component paired with the most frequently occurring member of the first pair. Thus, if the first pair chosen is pair A-E and the program must choose between pair A-D and pair E-F, the program may determine which of component types A and E occurs most frequently and select the corresponding component type D or F, respectively. Fourth, the program simply may select the component appearing in the pair that occurs first in the list.

If the program uses the first approach to select the third component, it selects component type D since the board contains more type D components than any other remaining type (Figure 6). The first component group 112 thus includes type A, type D, and type E components.

After the first component group 112 is complete, the program strikes all component pairs containing any of the three selected component types A, D, E and repeats the

process on the remaining pairs (B-F, F-G, B-C, C-G, C-F) until fewer than three component types remain. Any ungrouped components ("singles") are treated individually. For the circuit board 76 of Figure 3, the second component group 114 includes type B, type F, and type G components. Type C components are ungrouped and thus are treated as a single 116.

The grouping program also may generate for each group a count of the total number of components 118 appearing on the board. The first component group 112 (types A, D, E) includes sixty-four of the ninety-one components on the board, the second component group 114 (types B, F, G) contains twenty-five components, and the single 116 (type C) contains two components.

Referring to Figure 12, once the component types have been grouped, the component reels 120 corresponding to each group are placed side-by-side into a component table 122. The reels 124 holding the first group of components (types A, D, E) are first placed into the table, followed by the reels 126 of the second group (types B, F, G) and the reel 128 containing the single components (type C). Within each group, the reel containing the most frequently occurring components is placed between the other two components in the group. Therefore, the type A reel 130 and the type F reel 132 are the center reels in the first group 124 and the second group 126, respectively.

Referring to Figure 13, a shortest path optimization program uses the grouping instructions (Figure 4) created by the grouping program to calculate the shortest placement path for each component group. The optimization program first determines 134 the locations of all components in the first group (which the grouping instructions treat as a single entity) and calculates 136 the shortest path for

placement of these components. The program then determines 138 the locations of the components in the second group and calculates 140 the shortest placement path for the second component group. The optimization program then repeats 142 the shortest path calculation for all remaining component groups. When the program reaches the first single component type, it determines 144 the locations of all components of this type and calculates 146 the shortest path for placement of these components. The program repeats 148 this process 10 until no components remain.

Referring to Figures 14A and 14B, the shortest path optimization program generates a sequence listing 162 that determines the order in which components are placed on a circuit board 164. The sequence listing 162 identifies each 15 component to be placed on the board by its number 166 in the placement sequence, its position 168 on the board 164, its type 170, and the group 172 into which the component falls. For example, the first component 174 to be placed on the board 164 is a type-D component at $x=10\text{mm}$, $y=10\text{mm}$, and the 20 last component 176 to be placed is a type-C component at $x=25\text{mm}$, $y=40\text{mm}$. The arrows between components in Figure 14B show the placement path associated with the sequence listing 162.

Within the sequence listing 162 are subsequences 25 178, 180 that guide the placement of components within the component groups. In the first subsequence 178, all Group I components (type A, D, and E components) are placed on the board 164, and in the second subsequence 180, all Group II components (type B, F, and G components) are placed. As the 30 sequence listing 162 shows, the first subsequence 178 is completed before the second subsequence 180 begins. After all grouped components are placed, the single components 176 (type C components) are placed.

Alternatively, once the shortest placement path has been calculated for each component group, the end points of the placement paths may be matched up to determine the order in which the groups are placed. For example, in Figures 14A and 14B, the (40,10) endpoint of Group I is closest to the (35,20) endpoint of Group II. Likewise, the (10,10) endpoint of Group I is closest to the (25,40) endpoint of the single component. Therefore, the components likely would be placed in the following order: Single, Group I, Group II. In this situation, the type C component would be placed first in the sequence, the Group I components would be placed at positions 2 through 18 in the sequence, and the Group II components would be placed at positions 19 through 27 in the sequence. When endpoint matching is used, the placement order of components within a group may be inverted to allow the endpoints of the group's placement path to match up with the endpoints of adjacent groups.

The grouping program and the shortest path optimization algorithm also may be used in systems having multiple placement machines. In these systems, large component groups may be divided among several placement machines to balance the cycle time of each machine.

Referring to Figure 15, in an alternative embodiment, the grouping program improves component grouping by ensuring that closely situated components always are counted as a component pair. In the grid of Figure 7, components 154 and 156 would not be counted as a pair, even though they are of different types and are closely situated, because they lie on opposite sides of grid line X1 and therefore do not fall into the same grid block. With an overlapping grid, however, the components, if situated closely enough, are certain to fall within same grid block.

Grid block 1-2 is defined along the x-axis by the left edge 158 of the circuit board 150 and by grid line X1' and is defined along the y-axis by grid lines Y2a and Y2b. The location of grid line X1' is offset a small distance
5 beyond the location of the original grid line X1, preferably about two millimeters. Grid block 2-2 is defined along the x-axis by grid lines X2a and X2b and along the y-axis by grid lines Y2a and Y2b. The location of grid line X2b is offset approximately two millimeters to the left of the
10 location of the original grid line X1. Therefore, grid blocks 1-2 and 2-2 overlap by distance of approximately four millimeters, enough to allow at least one of the components 154, 156 to fall into both grid blocks, which ensures that the components 154, 156 are treated as a pair.

15 If both components 154, 156 lie within the overlap region 160, the components 154, 156 will be treated as a pair in both block 1-2 and block 2-2. To prevent the components 154, 156 from contributing twice to the pair's grid count, the grouping program must analyze the
20 overlapping grid blocks 1-2 and 2-2 for additional occurrences of the pair formed by components 154 and 156. If either block 1-2 or block 2-2 contains an additional occurrence of the pair, or if both blocks do, the presence of the pair in the overlap region 160 will not affect the
25 grid count. But if neither block 1-2 nor block 2-2 contains an additional occurrence of the pair, the grouping program must subtract one from the grid count.

Other embodiments are within the scope of the following claims. For example, component groups may contain
30 two, instead of three, component types. For component placement machines that are able to pick from four or more adjacent components without a reduction in performance, the component groups may include four or more component types.

In addition, optimization algorithms other than the shortest path algorithm may be used.

What is claimed is:



This Sheet Has Been Replaced



1 1. A method of automatically controlling the
2 placement of components on a circuit board, comprising
3 creating a group containing two or more types of
4 components to be placed on the circuit board, and
5 developing a placement path by which any component
6 within the group may be placed on the circuit board at any
7 point along the placement path.

1 2. The method of claim 1 wherein creating a group
2 of components comprises
3 identifying two types of components that are to be
4 closely situated at many locations on the circuit board, and
5 defining the group to contain components of the two
6 types.

1 3. The method of claim 2 wherein creating a group
2 of components further comprises
3 identifying a third type of components that is to be
4 closely situated to at least one of the other two types of
5 components at several locations on the circuit board, and
6 defining the group to contain components of all
7 three types.

1 4. The method of claim 1 wherein creating a group
2 of components comprises
3 defining several areas on the circuit board,
4 determining which types of components appear in each
5 of the areas, and
6 defining the group to include types of components
7 that appear together in a large number of areas.

1 5. The method of claim 4 wherein the group
2 comprises two types of components that appear together in
3 more of the areas than any other two types of components.

1 6. The method of claim 4 wherein the areas overlap.



1 7. The method of claim 4 wherein the each of the
2 areas comprises a block defined by a grid.

1 8. The method of claim 1 wherein developing a
2 placement path comprises calculating substantially the
3 shortest path required to place all components in the group
4 on the circuit board.

1 9. The method of claim 1 further comprising
2 creating an additional group for every three types of
3 components to be placed on the circuit board, and
4 developing a placement path for each of the
5 additional groups.

1 10. The method of claim 9 wherein the placement
2 path for each additional group begins where the placement
3 path for a previous group ends.

1 11. The method of claim 1 further comprising
2 placing components on the circuit board according to the
3 placement path.



1 12. A method of automatically controlling the
2 placement of components on a circuit board comprising
3 creating a group containing three types of
4 components by
5 a) dividing the circuit board into several
6 blocks defined by a grid,
7 b) determining which types of components to be
8 located on the circuit board appear together within each of
9 the blocks,
10 c) selecting two types of components that
11 appear together in more blocks than any other two types of
12 components,
13 d) selecting a third type of components that
14 appears with one of the other two types of components in
15 more blocks than any other two types of components, and
16 e) defining the group to contain components of
17 the three selected types,
18 calculating substantially the shortest path required
19 to place all of the components in the group on the circuit
20 board,
21 creating additional groups for every three types of
22 components remaining, and
23 for each additional group, calculating the shortest
24 path required to place all components in the group on the
25 circuit board, wherein the path begins where a previous
26 group's path ends.



1 13. A software program, stored on a storage medium,
2 for automatically controlling the placement of components on
3 a circuit board comprising

4 a routine for creating a group containing two or
5 more types of components to be placed on the circuit board,
6 and

7 a routine for developing a placement path by which
8 any type of component within the group may be placed on the
9 circuit board at any point along the placement path.

1 14. An apparatus for controlling placement of
2 components on a printed circuit board comprising

3 a component grouper that creates a group containing
4 two or more types of components to be placed on the circuit
5 board, and

6 a path generator that develops a placement path by
7 which any type of component within the group may be placed
8 on the circuit board at any point along the placement path.

1 15. The apparatus of claim 14 wherein the component
2 grouper identifies two types of components that are to be
3 closely situated at many locations on the circuit board and
4 defines the group to contain components of the two types.

1 16. The apparatus of claim 15 wherein the component
2 grouper identifies a third type of components that is to be
3 closely situated to at least one of the other two types of
4 components at several locations on the circuit board and
5 defines the group to contain components of all three types.



1 17. The apparatus of claim 14 wherein the component
2 grouper defines several areas on the circuit board and
3 determines which types of components appear in each of the
4 areas.

1 18. The apparatus of claim 17 wherein the group
2 comprises types of components that appear together in a
3 large number of areas.

1 19. The apparatus of claim 17 wherein the group
2 comprises two types of components that appear together in
3 more of the areas than any other two types of components.

1 20. The apparatus of claim 17 wherein the areas
2 overlap.

1 21. The apparatus of claim 17 wherein each of the
2 areas comprises a block defined by a grid.

1 22. The apparatus of claim 14 wherein the component
2 grouper creates an additional group for every three types of
3 components to be placed on the circuit board.

1 23. The apparatus of claim 22 wherein the path
2 generator develops a placement path for each of the
3 additional groups.

1 24. The apparatus of claim 23 wherein the placement
2 path for each additional group begins where the placement
3 path for a previous group ends.

1 25. The apparatus of claim 14 wherein the path
2 generator calculates substantially the shortest path
3 required to place all components in the group on the circuit
4 board.



1 26. An apparatus for automatically controlling the
2 placement of components on a circuit board comprising
3 a component grouper that divides the circuit board
4 into several blocks defined by a grid, determines which
5 types of components to be located on the circuit board
6 appear together within each of the blocks, selects two types
7 of components that appear together in more blocks than any
8 other two types of components, selects a third type of
9 components that appears with one of the other two types of
10 components in more blocks than any other two types of
11 components, creates a first component group containing the
12 three selected types of components, and creates additional
13 groups for every three remaining types of components, and
14 a path generator that calculates substantially the
15 shortest path required to place all of the components in the
16 first group on the circuit board, and for each additional
17 group, calculates the shortest path required to place all
18 components in the group on the circuit board, beginning
19 where the placement path for a previous group ends.

1 27. A method of defining a sequence for placing
2 components of multiple types in predefined locations on a
3 circuit board, comprising
4 organizing the components in groups each containing
5 at least two of the types of components,
6 placing components of a given one of the groups, and
7 thereafter placing components of another one of the
8 groups.

1 28. The method of claim 27 wherein all of the
2 components of the given one of the groups are placed before
3 any components of the other one of the groups are placed.



1 29. The method of claim 27 wherein
2 the components of the given one of the groups are
3 placed in an order such that any position in the order may
4 be occupied by a component of any of the types contained in
5 the group.

1 30. The method of claim 29 wherein the order in
2 which the components are placed is determined by the
3 shortest path required to place the components in the given
4 one of the groups.

1 31. The method of claim 27 wherein the types of
2 components contained in each of the groups are determined by
3 the frequency with which components of different types
4 appear in close proximity to each other.

1 32. The method of claim 31 wherein one of the
2 groups contains the two types of components that most
3 frequently appear in close proximity to each other.

1 33. The method of claim 32 wherein the one of the
2 groups also contains a third type of components.

1 34. The method of claim 27 wherein the components
2 are grouped based upon how frequently components of
3 different types appear together within predefined placement
4 areas.

1 35. The method of claim 27 wherein each of the
2 groups contains three types of components.



1 36. A method of placing components of multiple
2 types in accordance with a sequence defining an order in
3 which the components are placed in predefined locations on a
4 circuit board, comprising

5 in a subsequence of the sequence, placing multiple
6 components which belong only to a first group of at least
7 two of the types of components, and

8 repeating the prior step for at least one additional
9 group of at least two different types of components.

1 37. The method of claim 36 wherein in the
2 subsequence, the components are placed such that any
3 position in the subsequence may coincide with any of the
4 predefined locations associated with the types of components
5 contained in the first group.

1 38. The method of claim 36 wherein the order in
2 which the components are placed is determined by the
3 shortest path required to place the components in the given
4 one of the groups.

1 39. The method of claim 36 wherein the types of
2 components in each of the groups are determined by the
3 frequency with which components of different types appear in
4 close proximity to each other.

1 40. The method of claim 39 wherein one of the
2 groups contains the two types of components that most
3 frequently appear in close proximity to each other.

1 41. The method of claim 40 wherein the one of the
2 groups also contains a third type of components.

1 42. The method of claim 36 wherein the components
2 are grouped based upon how frequently components of
3 different types appear together within predefined placement
4 areas.



1 43. The method of claim 36 wherein each of the
2 groups contains three types of components.

1 44. A system for placing components on a circuit
2 board comprising

3 a component table that holds the components to be
4 placed on the circuit board,

5 a placement machine configured to pick the
6 components from the component table and place the components
7 on the circuit board,

8 a positioning table configured to hold the circuit
9 board and to position the board for component placement, and

10 at least one controller that governs operation of
11 the placement machine and the positioning table, wherein

12 the components are stored in the component
13 table in groups containing at least two types of
14 components,

15 the placement machine is capable of picking any
16 type of component from a group in the component
17 table without a noticeable loss of speed, and

18 the controller operates the placement machine
19 and the positioning table such that all components
20 of one of the groups are placed on the board before
21 any of the components of another of the groups.

1 45. The system of claim 44 wherein the controller
2 further operates the placement machine and the positioning
3 table such that the components in each of the groups are
4 placed in a path in which any type of component in a group
5 may be placed at any position along the path.



1 46. The system of claim 44 wherein the controller
2 further operates the placement machine and the positioning
3 table such that the components in each of the groups are
4 placed on the circuit board according to a shortest path
5 optimization.

1 47. The system of claim 44 wherein the types of
2 components contained in each of the groups are determined by
3 the frequency with which components of different types
4 appear in close proximity to each other.

1 48. The system of claim 47 wherein one of the
2 groups contains the two types of components that most
3 frequently appear in close proximity to each other.

1 49. The system of claim 48 wherein the one of the
2 groups also comprises a third type of components.

1 50. The system of claim 44 wherein the types of
2 components contained in each of the groups are determined by
3 the frequency with which components of different types
4 appear together within predefined areas on the circuit
5 board.

1 51. The system of claim 44 wherein each of the
2 groups comprises at least three components.

1 52. The system of claim 44 wherein the placement
2 machine comprises a turret-style machine.

1 53. The system of claim 44 wherein the component
2 table comprises components mounted on reels of tape.

1 54. The system of claim 44 wherein the positioning
2 table comprises an x-y table.



- 1 55. A system for placing components on a circuit
2 board comprising
3 a placement machine configured to place the
4 components according to groups containing at least two types
5 of components, and
6 a controller that governs the operation of the
7 placement machine such that components of a given one of the
8 groups are placed on the circuit board and thereafter
9 components of another one of the groups are placed.
- 1 56. The system of claim 55 wherein the controller
2 governs the operation of the placement machine such that all
3 components of the given one of the groups are placed before
4 any components of the other one of the groups are placed.
- 1 57. The system of claim 55 wherein the controller
2 further governs the operation of the placement machine such
3 that the components in each of the groups are placed
4 according to a path in which a component of any type in the
5 group may be placed at any position along the path.
- 1 58. The system of claim 55 wherein the controller
2 further governs the operation of the placement machine such
3 that the components in each of the groups are placed on the
4 circuit board according to a shortest path optimization.
- 1 59. The system of claim 55 wherein the types of
2 components contained in each of the groups are determined by
3 the frequency with which components of different types
4 appear in close proximity to each other.
- 1 60. The system of claim 59 wherein one of the
2 groups contains the two types of components that most
3 frequently appear in close proximity to each other.
- 1 61. The system of claim 60 wherein the one of the
2 groups also comprises a third type of components.



1 62. The system of claim 55 wherein the types of
2 components contained in each of the groups are determined by
3 the frequency with which components of different types
4 appear together within predefined areas on the circuit
5 board.

1 63. The system of claim 55 wherein each of the
2 groups comprises at least three components.

1 64. The system of claim 55 wherein the placement
2 machine comprises a turret-style machine.

1 65. The system of claim 55 further comprising a
2 component table that stores the components such that the
3 components within each group occupy adjacent positions in
4 the component table.